CHAPTER V

RESEARCH

A. GENERAL

RESEARCH AS RELATED TO TROPICAL CYCLONES WAS LIMITED DUE TO THE LACK OF AUTHORIZED PERSONNEL FOR THE 1959, 1960 AND 1961 SEASONS. A TOTAL OF SIX OFFICERS ARE NOW APPROVED FOR 1962; HOWEVER, THE TWO VACANCIES HAVE NOT AS YET BEEN MANNED.

THE "ANNUAL TYPHOON REPORT" IS PREPARED AND PUBLISHED AS A STATISTICAL AND DESCRIPTIVE RECORD AFTER THE SEASON IS OVER IN DECEMBER. THE PUBLICATION DATE VARIES FROM 15 MARCH TO 15 APRIL. THE REMAINDER OF THE TIME THROUGH JUNE IS DEVOTED TO RESEARCH PROJECTS, LEAVE AND TRAINING. WITH THE ANTICIPATED INCREASE OF PERSONNEL, IT IS HOPED THAT MUCH OF THE REPORT CAN BE WRITTEN DURING THE 1962 TYPHOON SEASON, THAT THE METEOROLOGICAL DISCUSSIONS CAN BE EXPANDED AND THAT FUNDS WILL BE AVAILABLE TO ENLARGE THIS REPORT. AN EARLIER PUBLICATION DATE IS NOT ANTICIPATED; HOWEVER, THE PERIOD BETWEEN DECEMBER AND PUBLICATION DATE WILL BE DEVOTED TO PROVIDING A MORE COMPLETE REPORT.

THE PROBLEMS ENCOUNTERED BY JTWC IN THE PAST THREE YEARS HAVE BEEN GREATER IN NUMBER THAN THOSE SOLVED DURING THE RESEARCH PERIOD. THE INCREASE IN MANNING OFFERS AN OPPORTUNITY TO MINIMIZE THESE PROBLEMS.

RESEARCH WILL BE DIVIDED INTO THREE TYPES FOR THE COMING SEASON:

1. SIMPLIFICATION OF FORECAST PROCEDURES
2. IMPROVEMENT OF THE FORECAST TECHNIQUES
3. EXAMINATION OF THE TROPICAL CYCLONE, WHICH WILL INCLUDE A DOCUMENTATION OF THE CYCLONE FROM THE FORMATION TO TYPHOON STAGE, AND TO OBTAIN MORE INFORMATION ABOUT THE STRUCTURE OF THE TYPHOON EYE.

PROJECTS DISCUSSED IN THIS CHAPTER ARE AS FOLLOWS:

1. A TEST OF THE ARAKAWA METHOD OF FORECASTING TYPHOON MOVEMENT AND SURFACE PRESSURE
2. MILLER-MOORE METHOD TESTED AND APPLIED IN THE WESTERN PACIFIC
3. WACHHOLZ COORDINATION CHART

A TEST OF THE ARAKAWA METHOD OF FORECASTING TYPHOON MOVEMENT AND SURFACE PRESSURE

By CHARLES G. WALDRON, LT, USNR

The Arakawa method of typhoon forecasting was developed by Dr. H. Arakawa and the staff of the Meteorological Research Institute, Tokyo, Japan. It is a statistical study based on the Veigas-Miller screening procedure used to develop a similar method of forecasting Atlantic hurricane movement. Three sets of regression equations were developed. One used surface data exclusively, another used 700 mb data, and the third used both. Due to the limited time and personnel available, only one method could be tested for this study. The set of equations using surface data exclusively was chosen because it would be the most useful as an operational forecasting tool. The main advantage in using surface data only is that a forecast can be made every six hours instead of every twelve hours if upper air data is used. In addition, the reliability of a forecasting technique depends directly on the quality and quantity of the reports used in its preparation. The paucity of upper air reports in the Western North Pacific limits the usefulness of an objective forecast using that data. The Miller-Moore method has proven a valuable exception.

The regression equations for the Arakawa method were derived from five years of data covering the period 1956-1960. The pressure pattern was obtained by using a grid of 91 points at intervals of 5 degrees of latitude and of longitude relative to the typhoon center (Fig. 1). The set of equations for 24 hour and 48 hour forecasts computed by the IBM 704 are on the following page. Equations are also available for 12 hour forecasts, but they were not evaluated due to their limited usefulness.

A test was made on the twenty typhoons which occurred in the Western North Pacific during the 1961 season. Positions for latitude and longitude and the 12 and 24 hour previous positions were taken from the typhoon best track charts. The pressures were obtained from 1/15,000,000 mercator projection charts using a grid that was true at 15N. The charts used were ones which had been analyzed during the season. The central pressures and 12 hour previous pressures were obtained by converting best track surface wind speeds using the Wachholz graph. The verifying pressures were obtained by the same method. The forecasts were made only from the 0000Z and 1200Z charts so that the best track Miller-Moore forecast for the same period could be used as a comparison. More Miller-Moore 24 hour forecasts were made from the same data because that method requires only 12 hour previous position vice the 24 hour positions required by Arakawa. No objective 48 hour forecast technique was available for comparison. A total of one hundred and fourteen 48 hour forecasts and one hundred and fifty three 24 hour forecasts were made.

ARAKAWA 24-48 HOUR EQUATIONS

$$LAT_{24} = -112.5 + 2.2797LAT_0 + 0.1284P_{90} + 0.1821P_{26} - 1.254LAT_{-12} - 0.0692P_{52} - 0.1293P_{39}$$

$$LONG_{24} = -589.6 + 1.6812LONG_0 + 0.7209LAT_0 + 0.2443P_{89} + 0.3469P_{21} - 0.7516LONG_{-24} - 0.6155LAT_{-12}$$

$$P_{24} = -1581.9 + 0.8613P_0 + 0.9063P_6 + 1.0163P_{46} + 1.1259P_{21} - 0.3225P_{-24} - 0.3547LONG_{-24} - 0.9921P_{63}$$

$$LAT_{48} = -106.6 + 2.8977LAT_0 + 0.2914P_{40} + 0.2132P_{90} + 0.2034P_{25} - 1.8073LAT_{-12} - 0.5396P_{46} - 0.0613P_{50}$$

$$LONG_{48} = -1037.6 + 1.8948LONG_0 + 2.1311LAT_0 + 0.6461P_{13} + 0.6245P_{89} - 1.0458LONG_{-24} - 1.7983LAT_{-12} - 0.2289P_{17}$$

$$P_{48} = -1790.4 + 0.6493P_0 + 2.6177P_6 + 1.4297P_{46} - 0.5141P_{-12} - 0.6288LONG_{-24} - 1.3597P_{63}$$

P_X = PRESSURE AT GRID POSITION X
LAT_0 = LATITUDE OF TYPHOON CENTER AT CHART TIME
$LONG_0$ = LONGITUDE OF TYPHOON CENTER AT CHART TIME
LAT_{-X} = LATITUDE OF CENTER AT X HOURS PRIOR TO CHART TIME
$LONG_{-X}$ = LONGITUDE OF CENTER AT X HOURS PRIOR TO CHART TIME
P_{-X} = CENTRAL PRESSURE AT X HOURS PRIOR TO CHART TIME

In both the 24 hour and 48 hour forecasts, the longitudinal error was greater than the latitudinal error. The scatter diagram (Fig. 2) of the 24 hour forecasts showed that one-third of the errors fall within the NE quadrant, but the largest ones occur in the SW quadrant. Forecasts which fail to predict recurvature of recurve too slowly produce errors that fall in that quadrant. The 48 hour scatter diagram (Fig. 3) also indicates that more than one-third of the errors are in the NE quadrant. The possibility exists that a correction could be determined to provide a more compact pattern; hovever, since only one year of independent data was tested against the five previous years, further evaluation is indicated before such a correction is made.

The errors for the 24 hour and 48 hour central pressure forecasts showed a bimodal distribution (Fig. 4 and 5). The higher peak on the 24 hour pressure histogram was at zero mb error, and the smaller was at -20 mb. The 48 hour histogram's peaks were of equal height. One was centered at zero mb error and the other at -30 mb. The verification of the pressure forecasts is to be considered less reliable than the position forecast since the former cannot be obtained directly. In addition, the best track position is usually more reliable than the surface wind speed obtained from the same source.

ERRORS OF FORECASTS USING THE ARAKAWA METHOD WITH 1961 BEST TRACK DATA

FORECAST	24 HOUR POSITION (MI)	24 HOUR PRESSURE (MB)	48 HOUR POSITION (MI)	48 HOUR PRESSURE (MB)
MEAN	113	-3	239	-3
STANDARD DIVIATION	74	22	162	26
NUMBER CASES	153	153	114	114

Since the test of this method used best track data, it cannot be compared with the operational forecast made by JTWC, nor can it be compared to the operational Miller-Moore error of 113 miles. The Miller-Moore method yielded an error of 96 miles using the best track data.

The Arakawa method shows promise of becoming a useful operational forecasting tool. Its 24 hour forecast compares favorably with the Miller-Moore method and has the added advantage of being available

EVERY SIX HOURS. THIS METHOD, WHICH PROVIDES 48 HOUR FORECASTS, IS THE FIRST TO BE EVALUATED BY JTWC AND WILL BE A WELCOME ADDITION TO THE LIMITED NUMBER OF LONG-RANGE FORECASTING TECHNIQUES PRESENTLY IN USE.

ARAKAWA GRID

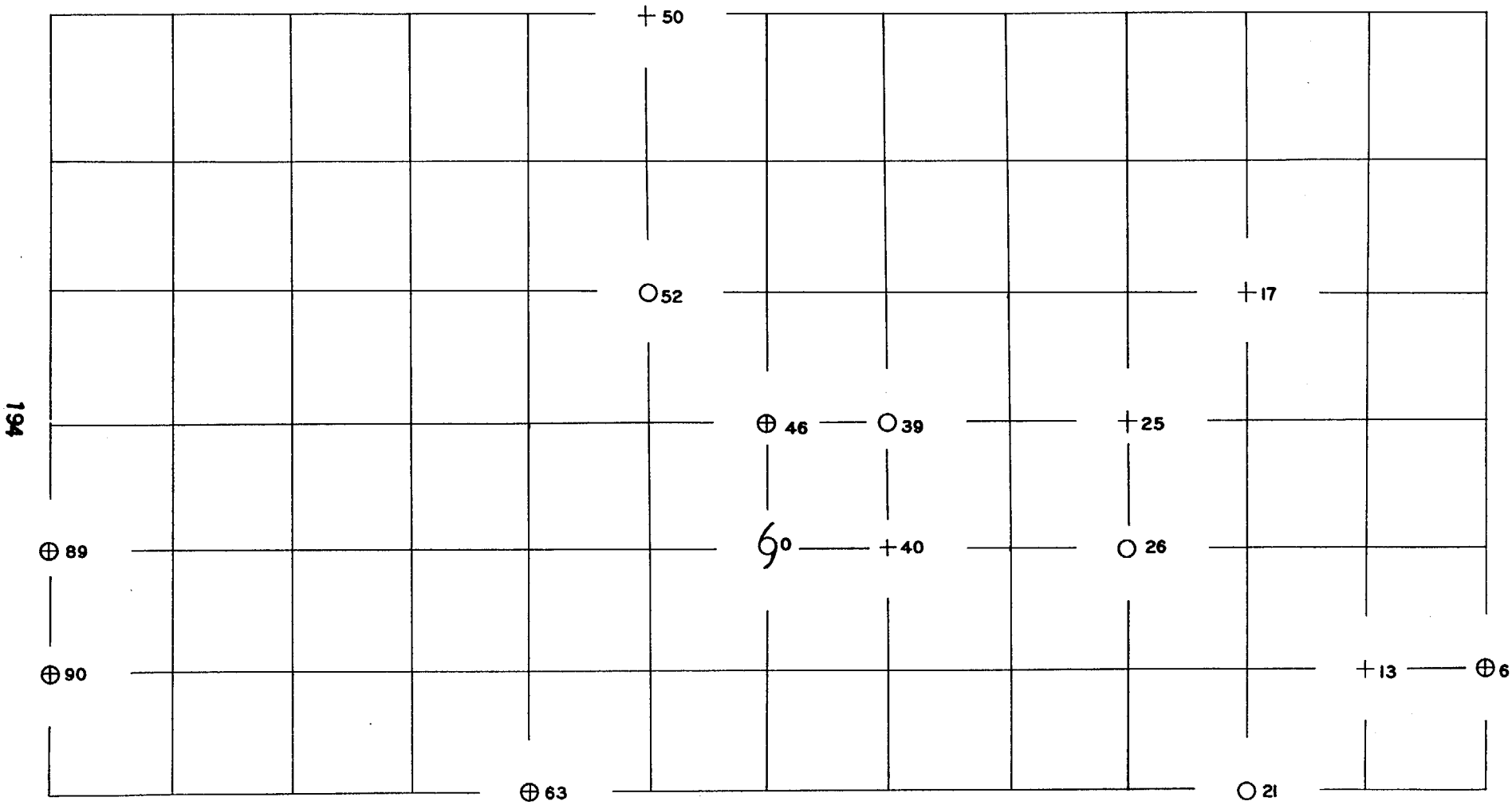


FIG 1

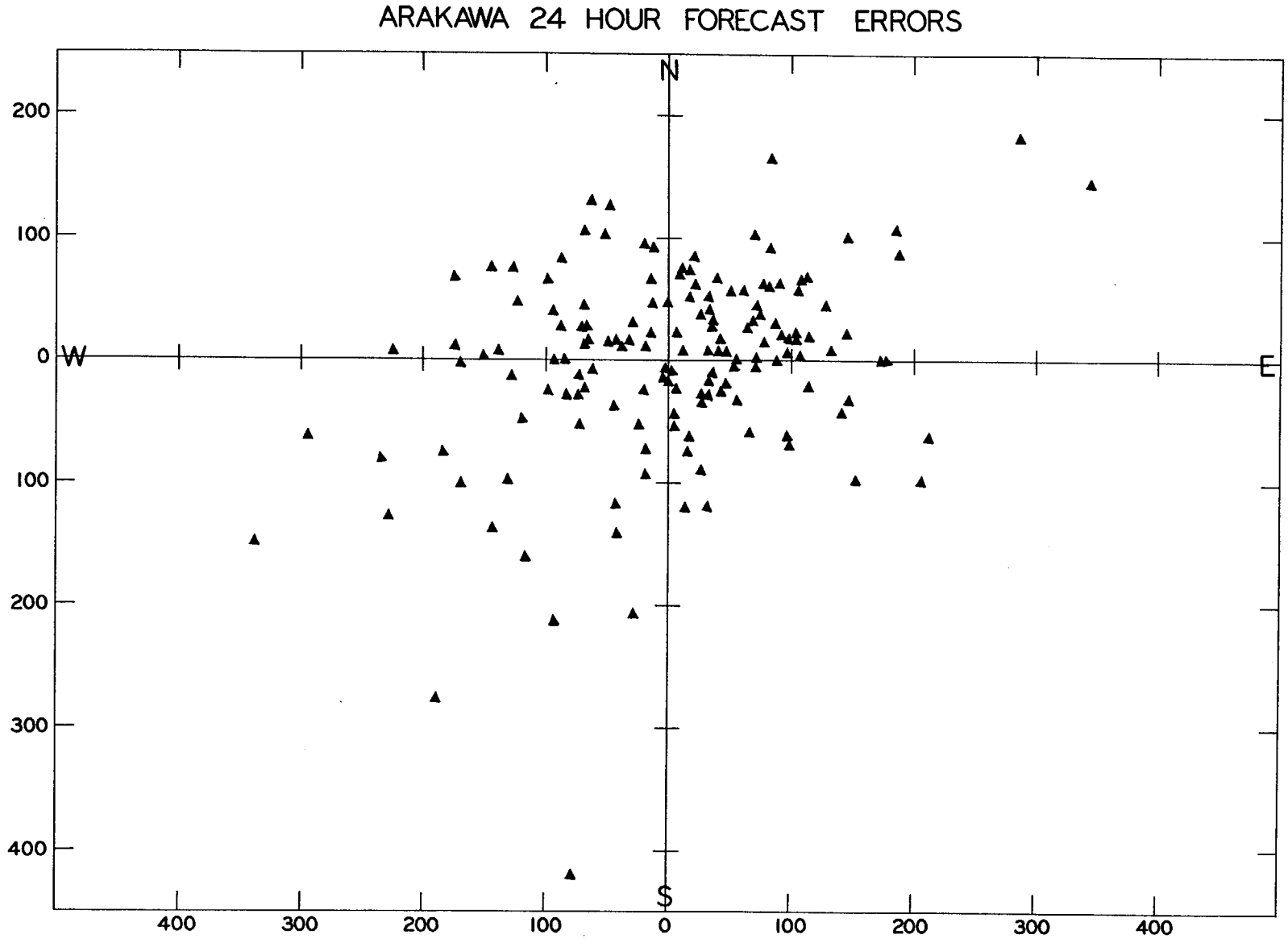

ARAKAWA 24 HOUR FORECAST ERRORS
N
W
E
S
200
100
0
100
200
300
400
400
300
200
100
0
100
200
300
400
MI N,E,S, OR W OF ACTUAL POSITION

FIG 2

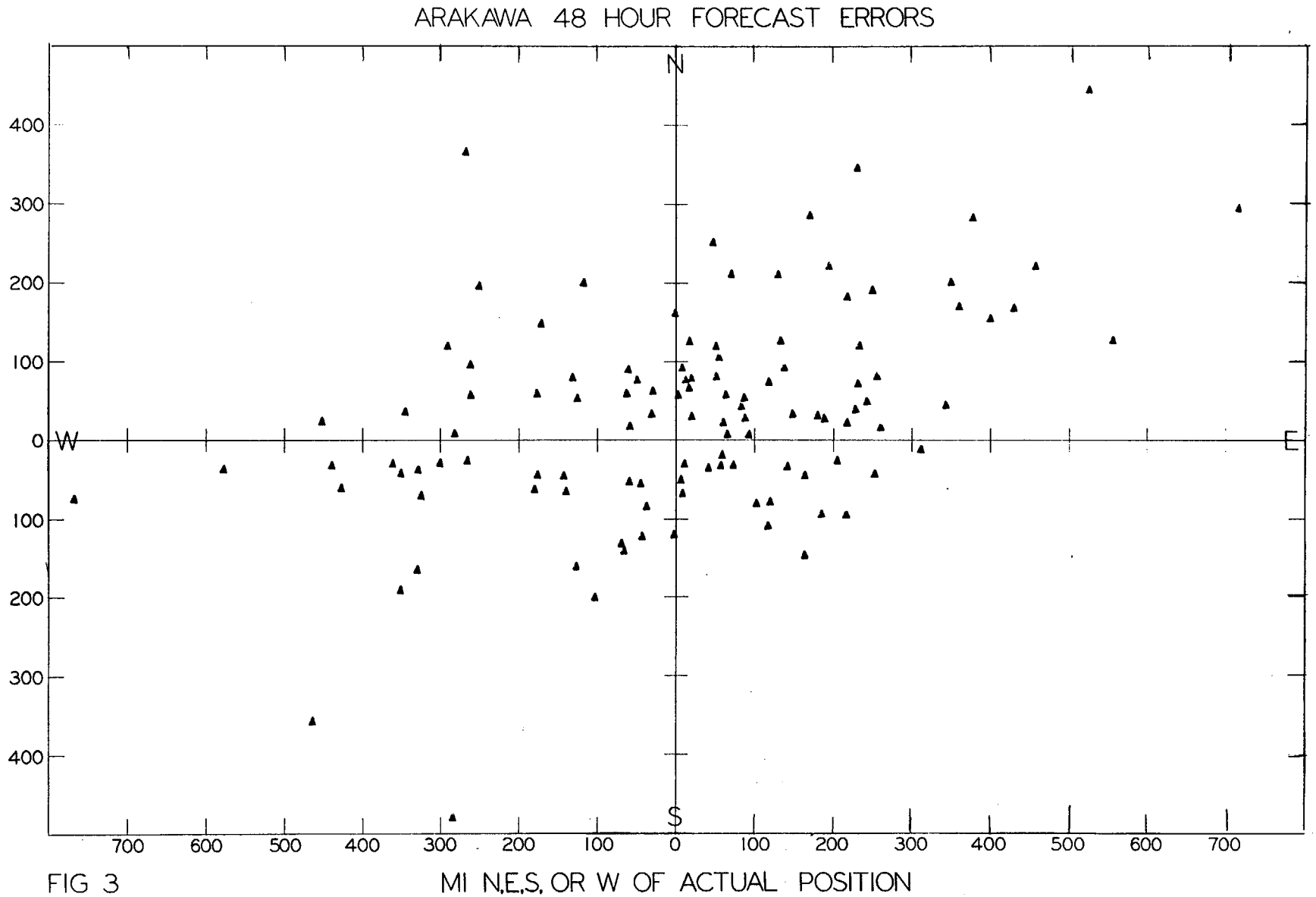

ARAKAWA 48 HOUR FORECAST ERRORS
N
S
W
E
400
300
200
100
0
100
200
300
400
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700
MI N.E.S. OR W OF ACTUAL POSITION

FIG 3

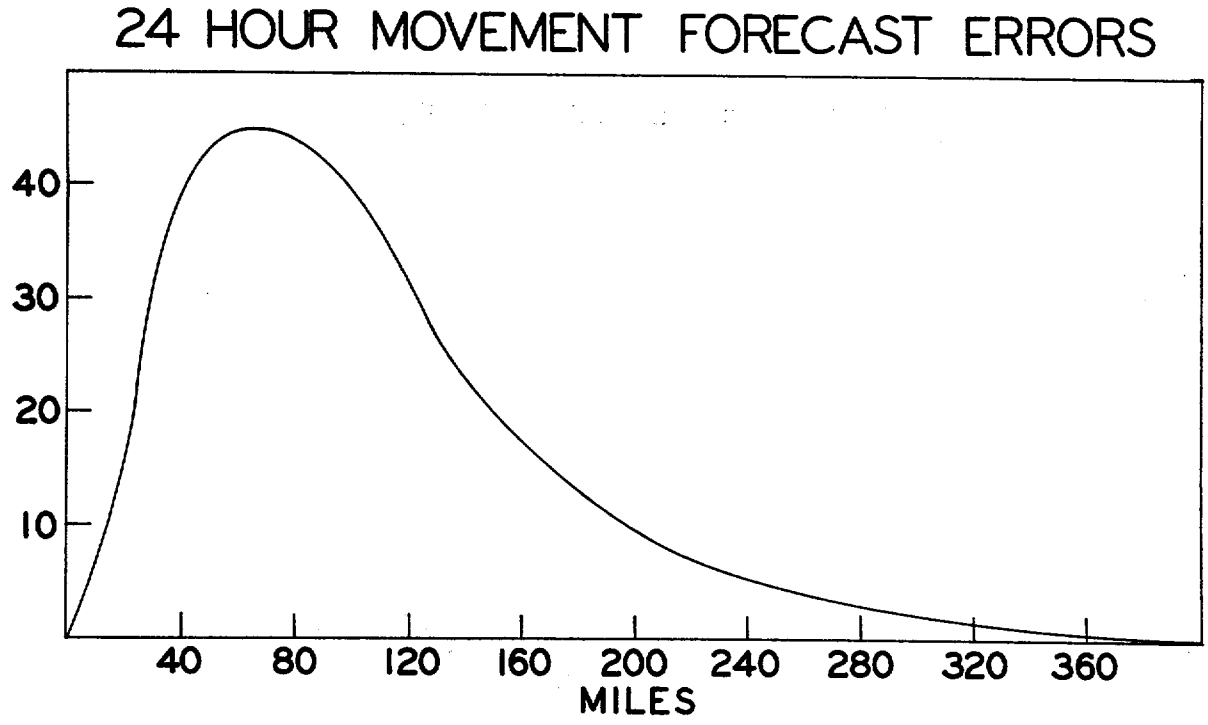
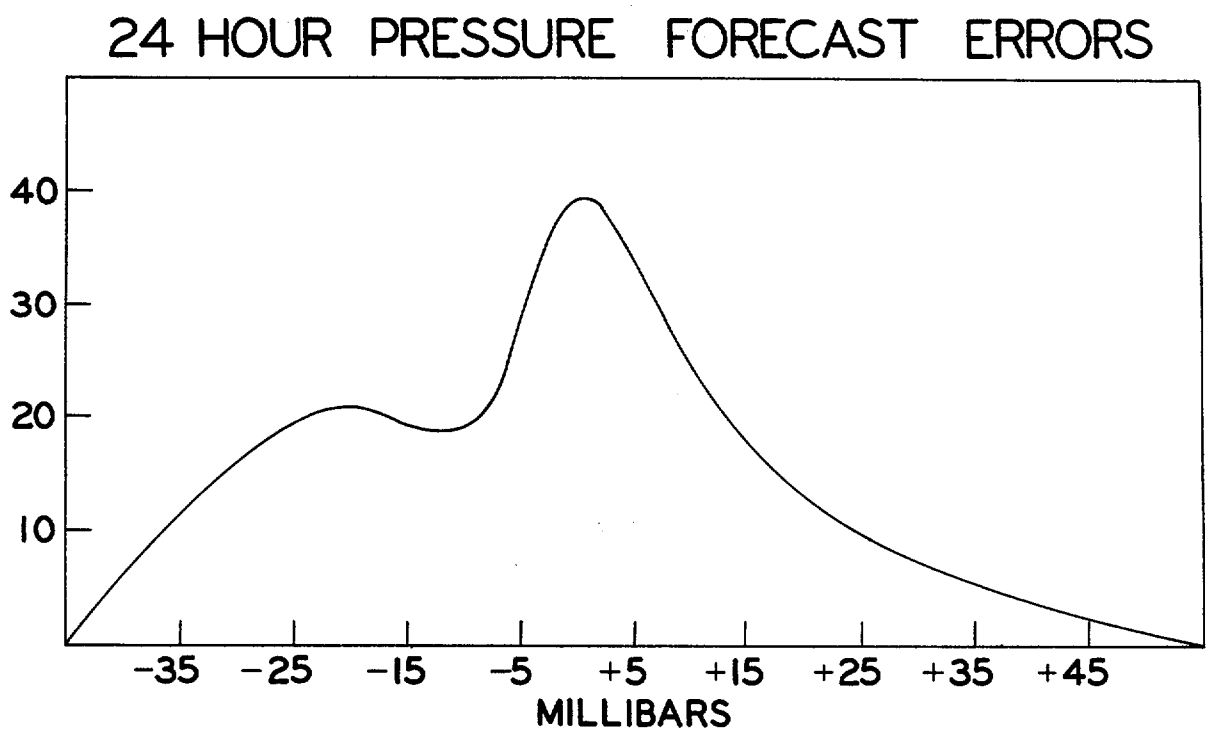

24 HOUR MOVEMENT FORECAST ERRORS
40
30
20
10
40
80
120
160
200
240
280
320
360
MILES

FIG 4


24 HOUR PRESSURE FORECAST ERRORS
40
30
20
10
-35
-25
-15
-5
+5
+15
+25
+35
+45
MILLIBARS

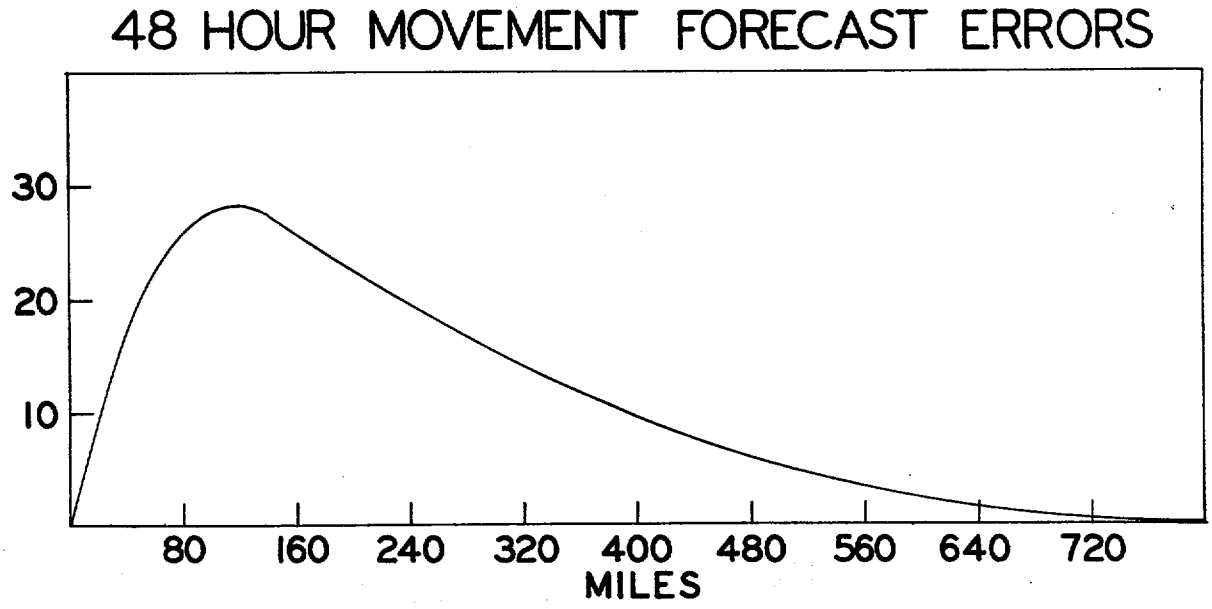
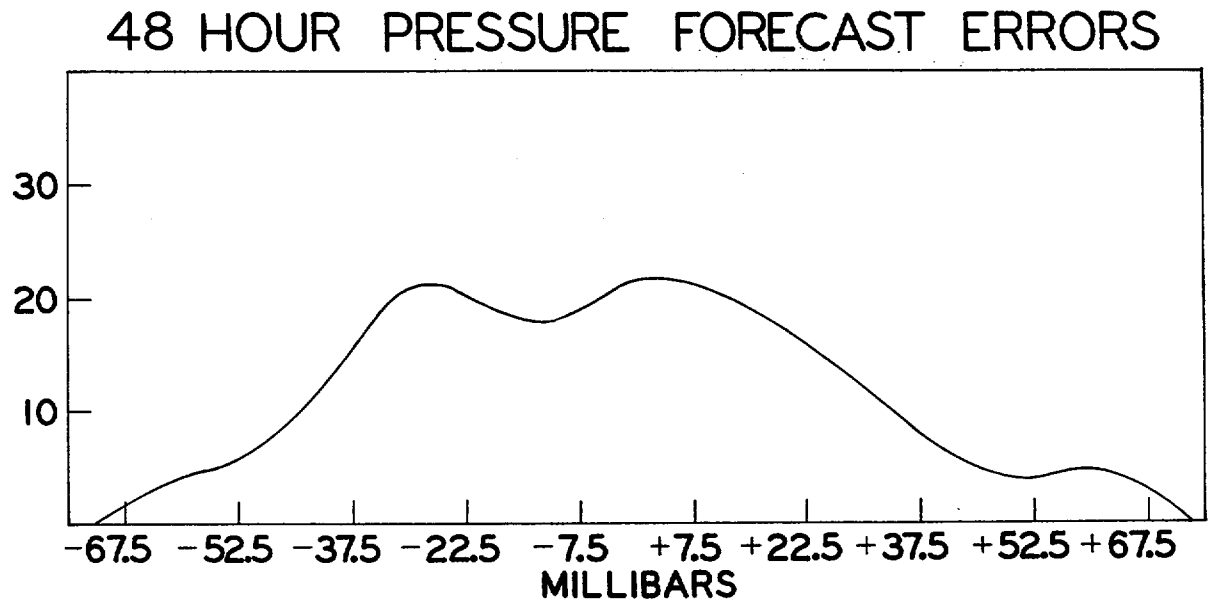

48 HOUR MOVEMENT FORECAST ERRORS
30
20
10
80
160
240
320
400
480
560
640
720
MILES

FIG 5


48 HOUR PRESSURE FORECAST ERRORS
30
20
10
-67.5
-52.5
-37.5
-22.5
-7.5
+7.5
+22.5
+37.5
+52.5
+67.5
MILLIBARS

ARAKAWA 24 HOUR FORECAST ERRORS

TESS

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2600Z	68	14	-	-	67
2612Z	245	-	80	-	234
2700Z	168	-	2	-	168
2712Z	186	69	-	-	172
2800Z	72	29	-	-	67
2812Z	52	15	-	-	49
2900Z	120	20	-	116	-
2912Z	113	-	25	113	-
3000Z	153	-	33	148	-
3012Z	153	-	43	141	-
3100Z	91	-	58	67	-
AVERAGE	129				

ALICE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1900Z	96	-	90	27	-
1912Z	76	31	-	68	-
2000Z	90	-	53	-	72
2012Z	370	-	149	-	335
2100Z	306	-	61	-	294
2112Z	167	75	-	-	144
AVERAGE	184				

BETTY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2412Z	17	-	17	-	-

ARAKAWA 24 HOUR FORECAST ERRORS

BETTY (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2500Z	26	24	-	8	-
2512Z	75	-	74	-	19
2600Z	55	-	51	-	24
2612Z	96	95	-	-	19
2700Z	234	-	212	-	91
2712Z	148	-	141	-	40
2800Z	208	-	206	-	26
2812Z	261	-	126	-	225
AVERAGE	124				

CORA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2412Z	72	3	-	71	-
2500Z	48	17	-	44	-
AVERAGE	60				

ELSIE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1412Z	144	130	-	-	63
1500Z	89	85	-	22	-
AVERAGE	117				

ARAKAWA 24 HOUR FORECAST ERRORS

HELEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2912Z	77	-	75	19	-
3000Z	120	-	120	15	-
3012Z	71	-	5	71	-
3100Z	184	165	-	85	-
3112Z	115	102	-	-	50
0100Z	39	11	-	-	36
0112Z	78	56	-	51	-
0200Z	107	3	-	107	-
0212Z	116	-	61	96	-
0300Z	98	5	-	98	-
0312Z	131	126	-	-	46
AVERAGE	103				

IDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
3012Z	184	-	98	153	-
3100Z	234	-	97	208	-
3112Z	339	182	-	288	-
AVERAGE	252				

JUNE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0312Z	110	64	-	91	-
0400Z	45	28	-	36	-
0412Z	76	73	-	19	-
0500Z	94	92	-	-	10
0512Z	78	-	11	-	74
0600Z	57	-	36	-	44
0612Z	46	15	-	-	43

ARAKAWA 24 HOUR FORECAST ERRORS

JUNE (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0700Z	92	28	-	-	87
0712Z	138	8	-	-	136
0800Z	16	-	15	-	3
0812Z	86	57	-	63	-
AVERAGE	76				

KATHY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1712Z	75	75	-	11	-
1800Z	122	104	-	71	-
AVERAGE	99				

LORNA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2212Z	124	105	-	-	68
2300Z	128	-	-	47	119
2312Z	80	15	78	-	-
2400Z	123	70	10	-	-
2412Z	110	66	-	-	97
2500Z	116	83	-	-	85
2512Z	130	66	111	-	-
2600Z	53	-	46	21	-
2612Z	67	67	-	-	12
AVERAGE	103				

ARAKAWA 24 HOUR FORECAST ERRORS

NANCY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0912Z	40	31	-	-	26
1000Z	24	22	-	-	11
1012Z	94	-	-	-	94
1100Z	81	45	-	-	67
1112Z	55	-	-	55	-
1200Z	8	-	8	-	-
1212Z	34	8	-	34	-
1300Z	51	41	-	34	-
1312Z	31	-	25	-	20
1400Z	66	-	61	19	-
1412Z	69	-	21	-	66
1500Z	49	49	-	-	-
1512Z	152	75	-	-	128
1600Z	134	47	-	-	124
1612Z	327	-	276	-	186
1700Z	427	-	420	-	76
AVERAGE	103				

OLGA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1000Z	58	51	-	17	-
AVERAGE	58				

PAMELA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1012Z	44	-	29	31	-
1100Z	205	87	-	190	-
1112Z	128	91	-	85	-
1200Z	44	-	34	28	-

ARAKAWA 24 HOUR FORECAST ERRORS

PAMELA (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1212Z	193	-	160	-	115
AVERAGE	123				

SALLY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2712Z	14	6	-	12	-
2800Z	139	49	-	129	-
2812Z	147	22	-	146	-
2900Z	40	-	29	27	-
2912Z	40	-	8	-	39
AVERAGE	76				

TILDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2912Z	224	8	-	-	224
3000Z	197	-	75	-	183
3012Z	196	-	107	-	167
0100Z	47	39	-	26	-
0112Z	175	100	-	148	-
0200Z	214	107	-	189	-
0212Z	118	57	-	106	-
0300Z	97	20	-	94	-
0312Z	222	-	64	212	-
0400Z	120	-	69	100	-
0412Z	68	-	31	59	-
0500Z	35	17	-	-	29
AVERAGE	143				

ARAKAWA 24 HOUR FORECAST ERRORS

VIOLET

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0600Z	150	3	-	-	150
0612Z	166	-	98	-	130
0700Z	96	-	94	-	18
0712Z	52	-	25	45	-
0800Z	106	21	-	105	-
0812Z	88	-	-	88	-
0900Z	101	16	-	98	-
0912Z	123	-	116	-	41
1000Z	201	-	138	-	141
1012Z	196	-	100	-	169
AVERAGE	128				

BILLIE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2500Z	91	-	29	-	84
2512Z	102	40	-	-	92
2600Z	50	47	-	-	11
2612Z	50	8	-	49	-
2700Z	136	45	-	127	-
2712Z	84	45	-	73	-
2800Z	120	-	22	115	-
AVERAGE	90				

CLARA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2812Z	100	62	-	78	-
2900Z	92	67	-	40	-
2912Z	96	60	-	81	-
3000Z	67	52	-	34	-

ARAKAWA 24 HOUR FORECAST ERRORS

CLARA (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
3012Z	140	6	-	133	-
3100Z	177	-	-	177	-
3112Z	396	145	-	345	-
0100Z	175	-	-	175	-
AVERAGE	154				

DOT

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1100Z	130	65	-	110	-
1112Z	90	30	-	88	-
1200Z	50	33	-	36	-
1212Z	66	15	-	-	65
1300Z	77	28	-	-	70
1312Z	176	12	-	-	174
1400Z	132	-	12	-	127
1412Z	65	-	7	-	60
1500Z	102	-	24	-	98
1512Z	75	-	27	-	72
AVERAGE	96				

ELLEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0612Z	20	12	-	-	16
0700Z	55	-	5	53	-
0712Z	37	-	16	34	-
0800Z	120	-	118	32	-
0812Z	68	26	-	65	-
0900Z	12	-	10	2	-
0912Z	85	-	-	-	85

ARAKAWA 24 HOUR FORECAST ERRORS

ELLEN (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1000Z	50	-	45	7	-
1012Z	60	-	54	7	-
1100Z	86	64	-	24	-
1112Z	45	6	-	43	-
1200Z	110	17	-	105	-
1212Z	86	37	-	75	-
AVERAGE	64				

ARAKAWA 48 HOUR FORECAST ERRORS

TESS

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2700Z	320	-	36	-	328
2712Z	580	-	38	-	579
2800Z	347	36	-	-	344
2812Z	316	120	-	-	291
2900Z	156	80	-	-	131
2912Z	137	52	-	-	126
3000Z	256	-	43	253	-
3012Z	206	-	97	184	-
3100Z	215	-	146	164	-
AVERAGE	281				

ALICE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2000Z	225	-	201	-	104
2012Z	94	77	-	-	50
2100Z	354	-	42	-	350
2112Z	768	-	75	-	768
AVERAGE	360				

BETTY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2512Z	163	-	108	116	-
2600Z	93	44	-	83	-
2612Z	70	-	55	-	45
2700Z	146	-	131	-	70
2712Z	69	-	67	9	-
2800Z	550	-	480	-	285
2812Z	576	-	358	-	464
AVERAGE	238				

ARAKAWA 48 HOUR FORECAST ERRORS

HELEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	S	ZONAL ERROR E	W
3012Z	94	29	-	88	-
3100Z	88	58	-	64	-
3112Z	161	161	-	-	-
0100Z	331	286	-	172	-
0112Z	71	67	-	16	-
0200Z	60	59	-	2	-
0212Z	218	23	-	217	-
0300Z	252	49	-	243	-
0312Z	94	8	-	94	-
AVERAGE	152				

IDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	S	ZONAL ERROR E	W
3112Z	568	126	-	555	-
AVERAGE	568				

JUNE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	S	ZONAL ERROR E	W
0412Z	294	221	-	195	-
0500Z	224	212	-	71	-
0512Z	258	252	-	48	-
0600Z	246	211	-	130	-
0612Z	74	63	-	-	30
0700Z	35	31	-	20	-
0712Z	132	120	-	51	-
0800Z	184	127	-	134	-
0812Z	98	82	-	51	-
AVERAGE	172				

ARAKAWA 48 HOUR FORECAST ERRORS

LORNA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2312Z	134	-	-	123	43
2400Z	185	-	-	44	176
2412Z	183	32	181	-	-
2500Z	253	71	231	-	-
2512Z	328	190	250	-	-
2600Z	223	200	-	-	118
2612Z	323	195	-	-	250
AVERAGE	233				

NANCY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1012Z	312	-	11	312	-
1100Z	145	-	34	141	-
1112Z	91	-	85	-	39
1200Z	48	34	-	-	31
1212Z	79	-	31	74	-
1300Z	34	-	30	12	-
1312Z	60	-	19	59	-
1400Z	128	126	-	16	-
1412Z	208	-	161	-	126
1500Z	154	-	140	-	66
1512Z	188	60	-	-	176
1600Z	226	148	-	-	172
1612Z	454	24	-	-	453
1700Z	448	367	-	-	267
AVERAGE	184				

ARAKAWA 48 HOUR FORECAST ERRORS

PAMELA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1112Z	408	201	-	350	-
1200Z	781	295	-	715	-
1212Z	456	168	-	431	-
AVERAGE	548				

SALLY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2812Z	280	182	-	217	-
2900Z	467	279	-	380	-
2912Z	505	222	-	457	-
AVERAGE	417				

TILDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
3012Z	442	-	33	-	441
0100Z	272	-	25	-	267
0112Z	267	58	-	-	262
0200Z	415	347	-	232	-
0212Z	684	445	-	525	-
0300Z	642	279	-	566	-
0312Z	388	170	-	360	-
0400Z	346	45	-	344	-
0412Z	104	55	-	87	-
0500Z	133	-	79	103	-
AVERAGE	370				

ARAKAWA 48 HOUR FORECAST ERRORS

VIOLET

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0700Z	278	9	-	-	227
0712Z	153	-	65	-	140
0800Z	120	-	120	-	3
0812Z	191	26	-	187	-
0900Z	260	16	-	260	-
0912Z	165	93	-	137	-
1000Z	80	77	-	14	-
1012Z	398	-	191	-	351
AVERAGE	206				

BILLIE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2600Z	330	-	70	-	324
2612Z	109	90	-	-	61
2700Z	151	34	-	149	-
2712Z	169	-	44	164	-
2800Z	242	-	94	216	-
AVERAGE	200				

CLARA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2912Z	54	-	34	42	-
3000Z	85	80	-	20	-
3012Z	65	-	32	58	-
3100Z	270	82	-	256	-
3112Z	425	156	-	400	-
0100Z	236	40	-	228	-
AVERAGE	189				

ARAKAWA 48 HOUR FORECAST ERRORS

DOT

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1200Z	267	120	-	234	-
1212Z	70	8	-	65	-
1300Z	87	60	-	-	64
1312Z	370	-	30	-	362
1400Z	308	29	-	-	300
1412Z	430	-	60	-	427
1500Z	347	-	165	-	330
1512Z	192	-	63	-	180
AVERAGE	259				

ELLEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0612Z	286	95	-	-	263
0700Z	206	-	26	205	-
0712Z	62	23	-	60	-
0800Z	163	-	78	120	-
0812Z	137	75	-	117	-
0900Z	63	18	-	-	60
0912Z	150	-	45	-	144
1000Z	54	-	50	6	-
1012Z	77	-	52	-	60
1100Z	100	95	-	7	-
1112Z	130	107	-	55	-
AVERAGE	130				

MILLER-MOORE METHOD TESTED AND APPLIED IN THE WESTERN PACIFIC

By Elmer A. Erdei, Lt (jg), USN

The Miller-Moore method was discussed in Chapter VII (Research) of the 1960 Annual Typhoon Report. At that time the 1959 data had not been completely evaluated. This series of investigations has provided results that are twofold. First, it apprises the original authors of results based on its use in the Western North Pacific. Secondly, it provides JTWC with a mathematical tool that may be continuously used as a guide to more accurate forecasting.

This method is based on Atlantic Hurricane data and was prepared by B. I. Miller and B. L. Moore. Briefly, the method consists of correlating the storm movement with a mean geostrophic wind and the past 12 hour storm movement. Using 700 mb data, the method involves separate determination of meridional and zonal forecasts of storm movement. The equations as developed by Miller and Moore are:

Initial latitude equal to or less than 27.5°

$$\bar{V} = 0.23v_7 + 0.65P_Y + 2.3 \qquad (1)$$

$$\bar{U} = 0.42u_7 + 0.54P_X - 2.4$$

Initial latitude more than 27.5°

$$\bar{V} = 0.71v_7 + 0.40P_Y + 3.0 \qquad (2)$$

$$\bar{U} = 0.61u_7 + 0.48P_X - 3.8$$

$\bar{U}$ = forecast mean 24 hour zonal speed of center movement (kts)

$\bar{V}$ = forecast mean 24 hour meridional speed of center movement (kts)

v_7 = first approximation: mean 700 mb geostropic wind between five pairs of points 7.5 degrees E and 7.5 degrees W of the storm center and extending from 5 degrees S to 5 degrees N of the center. If southward movement results - no further computation necessary for v_7.

Second approximation: add points at 7.5 degrees N of center to first calculation. If both of the first two approximations are less than 6.5 kts, use the larger - no further computation necessary for v_7.

THIRD APPROXIMATION: SAME AS SECOND BUT ADDING POINTS AT 10 DEGREES N OF CENTER TO SECOND APPROXIMATION. USE THE LARGEST OF THE THREE APPROXIMATIONS.

U_7 = MEAN 700 MB GEOSTROPIC WIND BETWEEN SEVEN PAIRS OF POINTS 5 DEGREES S OF THE INITIAL POSITION OF THE STORM CENTER AND 5 DEGREES N OF THE LATITUDE THAT THE $\overline{V}$ COMPUTATION INDICATES THE CENTER WILL REACH 12 HOURS AFTER CHART TIME.

PY = MEAN MERIDIONAL SPEED OF MOVEMENT OF CENTER FOR THE 12 HOURS PRIOR TO CHART TIME (KTS).

PX = MEAN ZONAL SPEED OF MOVEMENT OF CENTER FOR THE 12 HOURS PRIOR TO CHART TIME (KTS).

U_7 AND V_7 ARE COMPUTED FROM THE LATEST 700 MB CHART ON THE MILLER-MOORE GRID SHOWN HEREIN. HEIGHTS ARE TABULATED FOR EVERY $2\frac{1}{2}$ DEGREES. IN THE CASE OF THE MERIDIONAL COMPONENT, THE AVERAGE HEIGHT DIFFERENCE IS COMPUTED BETWEEN 5 DEGREES N AND S OF THE CENTER; HOWEVER, DEPENDING UPON THE RESULTING NORTHWARD SPEED OF THE STORM, THIS GRID MAY BE EXTENDED TO 7.5 OR 10 DEGREES N OF THE CENTER IN ACCORDANCE WITH THE SPECIFIED CRITERIA. IN THE CASE OF THE ZONAL COMPONENT, THE AVERAGE HEIGHT DIFFERENCE BETWEEN THE TWO HORIZONTAL ROWS IS COMPUTED; THE BOTTOM ROW BEING 5 DEGREES S OF THE INITIAL SURFACE POSITION OF THE STORM AND THE TOP ROW BEING 5 DEGREES N OF THE 12 HOUR MERIDIONAL FORECAST POSITION OF THE CENTER. THE AVERAGE MERIDIONAL AND ZONAL HEIGHT DIFFERENCES ARE THEN REDUCED TO METERS PER DEGREE AND CONVERTED TO GEOSTROPIC WIND (KTS) FOR THE CENTRAL LATITUDE USING THE GRAPH SHOWN HEREIN. $\overline{U}$ AND $\overline{V}$ ARE THEN SOLVED FOR, USING THE EQUATIONS (1) OR (2).

AFTER THE END OF THE 1960 TYPHOON SEASON IT WAS CONCLUDED THAT THIS METHOD COULD BE CORRECTED TO WORK BETTER IN THE WESTERN PACIFIC AREA. RECOMPUTING THE DATA FROM THE 1959 AND 1960 SEASONS PROVIDED A TOTAL OF THREE HUNDRED CASES FROM WHICH TO OBTAIN DATA FOR PX, PY AND TO COMPUTE NEW CONSTANTS.

RESULTS OF TWO YEARS DATA INDICATED THAT TWO CHANGES COULD BE MADE TO IMPROVE THE METHOD FOR THE WESTERN NORTH PACIFIC; FIRST, ADJUST THE MERIDIONAL AND ZONAL CONSTANTS SLIGHTLY, AND SECONDLY, ESTABLISH A DIFFERENT PROCEDURE FOR DETERMINING THE MOST SUITABLE POINT TO COMMENCE USE OF THE SECOND EQUATION.

APPARENTLY THE LATITUDE OF 27.5N, POINT OF CHANGE FROM THE FIRST TO THE SECOND FORMULA IS CONSIDERED TO BE THE AVERAGE LATITUDE OF THE SUBTROPICAL RIDGE LINE. THIS WOULD ALSO APPROXIMATE THE DIVIDING LINE BETWEEN THE INITIAL MOVEMENT BY THE CYCLONE TO THE W AND MOVEMENT TO THE E AFTER RECURVATURE. IN VIEW OF THE DIFFERENT PROBLEMS OF MOVEMENT, TWO EQUATIONS ARE NEEDED. OF COURSE, A MORE IDEAL

METHOD WOULD BE TO HAVE THREE FORMULAS, ONE FOR WESTERLY MOVEMENT, ONE FOR NORTHERLY MOVEMENT, AND ANOTHER FOR EASTERLY MOVEMENT. THIS IDEAL IS IMPOSSIBLE BECAUSE OF THE PROBLEM OF DECIDING WHICH OF THE FORMULAS TO USE. SOME SUCCESS HAS BEEN ACHIEVED IN FORECASTING THE POSITION OF THE RIDGE LINE, THEREFORE THE FIXED FIGURE OF 27.5 AS THE POINT TO CHANGE FORMULAS IS NOT ABSOLUTELY NECESSARY, ALTHOUGH IT IS AN EXCELLENT GUIDE. THUS, THE SECOND FORMULA IS NOW USED JUST AFTER POINT OF RECURVATURE. RECURVATURE IS DEFINED HERE AS THAT POINT AT WHICH THE CYCLONE CEASES MOVEMENT TO THE W OF N AND COMMENCES MOVING TO THE E OF N.

FROM 258 CASES S OF THIS DEFINITION OF POINT OF RECURVATURE, IT WAS DETERMINED THAT THE MERIDIONAL FORECAST ERRORS AVERAGED 1.1 KTS TO THE N, AND THE ZONAL FORECAST ERRORS AVERAGED 2.0 KTS TO THE E. NORTH OF THE POSITION OF RECURVATURE THERE WERE A TOTAL OF 50 CASES. THESE SHOWED THE MERIDIONAL FORECAST ERRORS AVERAGED 0.2 KTS TO THE S, AND THE ZONAL FORECAST ERRORS AVERAGED 1.6 KTS TO THE W.

USING THE ABOVE CORRECTIONS THE FOLLOWING MODIFIED EQUATIONS OF (1) AND (2) WERE DEVELOPED:

AT OR SOUTH OF THE POINT OF RECURVATURE

$$\bar{V} = 0.23v_7 + 0.65P_Y + 1.2 \qquad (3)$$

$$\bar{U} = 0.42u_7 + 0.54P_X - 0.4$$

NORTH OF THE POINT OF RECURVATURE

$$\bar{V} = 0.71v_7 + 0.40P_Y + 3.2 \qquad (4)$$

$$\bar{U} = 0.61u_7 + 0.48P_X - 5.4$$

DURING 1961 EQUATIONS (1), (2), (3) AND (4) WERE USED ON AN OPERATIONAL BASIS TO FORECAST THE MOVEMENT OF TROPICAL LOWS. THE AVERAGE FORECAST ERROR FOR EACH TYPHOON AND FOR THE YEAR IS SHOWN IN THE FOLLOWING TABLE. NOTE THAT THE INFORMATION HERE IS BASED ON OPERATIONAL POSITIONS, NOT ON BEST TRACK DATA. THE AVERAGE ERROR USING EQUATIONS (1) AND (2) FOR BEST TRACK POSITIONS WAS 96 MI.

TYPHOON	NO. OF CASES	MEAN FORECAST ERROR EQUATIONS (1) & (2)	MEAN FORECAST ERROR EQUATIONS (3) & (4)
TESS	12	95	93
ALICE	7	104	116
BETTY	11	94	87
CORA	3	142	89
ELSIE	3	158	114
HELEN	13	92	94
IDA	5	217	156
JUNE	14	133	93
KATHY	4	163	100
LORNA	10	141	108
NANCY	17	120	109
OLGA	3	70	53
PAMELA	7	161	131
SALLY	6	137	96
TILDA	14	138	124
VIOLET	11	149	147
BILLIE	8	104	140
CLARA	9	222	181
DOT	12	144	102
ELLEN	11	74	121
AVERAGE ERROR		129 MI	113 MI

IN VIEW OF THE ABOVE, IT WAS DECIDED TO INCLUDE THE 1961 FORECASTING ERRORS WITH THE DATA FOR 1959 AND 1960. THE EQUATIONS WHICH RESULTED FROM A TOTAL OF THREE YEARS DATA ARE SHOWN BELOW. IT IS PLANNED TO USE THESE ON AN OPERATIONAL BASIS DURING THE 1962 SEASON.

AT OR SOUTH OF THE POINT OF RECURVATURE

$$\overline{V} = 0.23v_7 + 0.65P_Y + 1.1 \qquad (5)$$

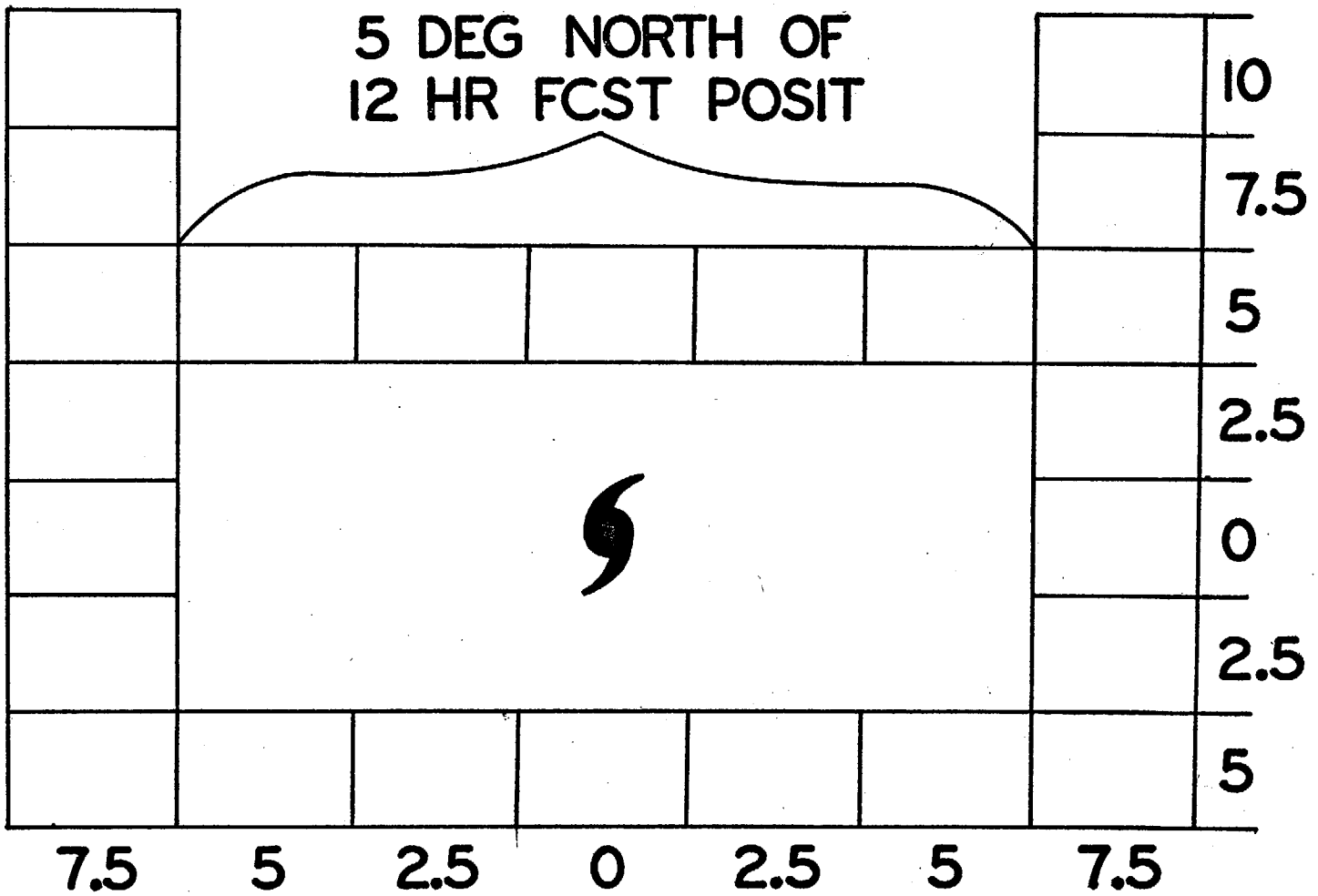
$$\overline{U} = 0.42u_7 + 0.54P_X - 0.2$$

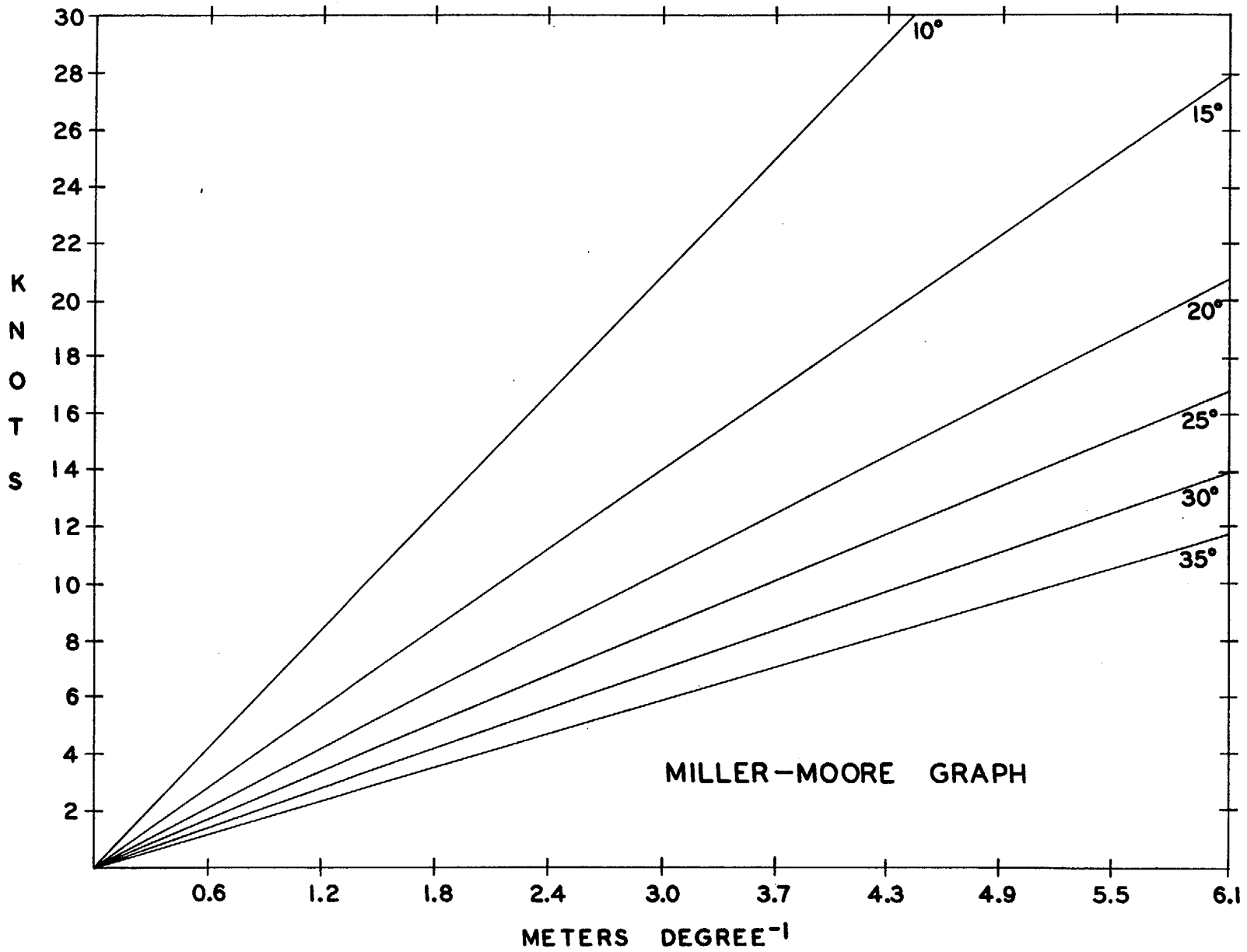
NORTH OF THE POINT OF RECURVATURE

$$\overline{V} = 0.71v_7 + 0.40P_Y + 3.6 \qquad (6)$$

$$\overline{U} = 0.61u_7 + 0.48P_X - 5.7$$

MILLER-MOORE GRID

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METERS DEGREE^{-1}

MILLER-MOORE 24 HOUR FORECAST ERRORS

TESS

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2512Z	217	158	-	155	-
2600Z	5	-	2	-	3
2612Z	78	-	37	-	71
2700Z	65	-	-	-	65
2712Z	65	62	-	11	-
2800Z	121	93	-	60	-
2812Z	113	62	-	97	-
2900Z	96	96	-	-	-
2912Z	135	65	-	120	-
3000Z	64	-	-	64	-
3012Z	97	25	-	95	-
3100Z	100	-	17	-	98
AVERAGE	96				

ALICE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1812Z	30	-	30	3	-
1900Z	57	-	47	20	-
1912Z	23	-	2	-	23
2000Z	73	-	5	-	73
2012Z	90	74	-	-	56
2100Z	203	65	-	-	192
2112Z	178	172	-	-	47
AVERAGE	93				

BETTY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2312Z	123	60	-	107	-
2400Z	150	-	16	150	-
2412Z	75	5	-	75	-
2500Z	74	48	-	62	-

MILLER-MOORE 24 HOUR FORECAST ERRORS

BETTY (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2512Z	70	-	14	70	-
2600Z	35	30	-	19	-
2612Z	65	64	-	-	15
2700Z	87	-	55	-	75
2712Z	93	-	85	-	43
2800Z	138	-	125	-	52
2812Z	211	-	93	-	173
AVERAGE	102				

CORA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2400Z	108	45	-	98	-
2412Z	107	37	-	102	-
2500Z	197	112	-	161	-
AVERAGE	137				

ELSIE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1400Z	128	97	-	80	-
1412Z	89	77	-	43	-
1500Z	208	75	-	188	-
AVERAGE	142				

HELEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2812Z	76	63	-	-	52

MILLER-MOORE 24 HOUR FORECAST ERRORS

HELEN (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2900Z	29	28	-	16	-
2912Z	34	-	10	33	-
3000Z	38	-	18	33	-
3012Z	59	39	-	43	-
3100Z	170	161	-	-	48
3112Z	122	80	-	-	91
0100Z	69	15	-	66	-
0112Z	45	37	-	-	32
0200Z	58	54	-	20	-
0212Z	73	-	63	41	-
0300Z	55	54	-	10	-
AVERAGE	69				

IDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2912Z	144	24	-	138	-
3000Z	182	-	21	174	-
3012Z	146	-	13	142	-
3100Z	163	-	3	163	-
3112Z	374	309	-	216	-
AVERAGE	202				

JUNE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0212Z	60	-	46	36	-
0300Z	86	23	-	86	-
0312Z	160	79	-	141	-
0400Z	128	43	-	124	-
0412Z	166	131	-	101	-
0500Z	117	115	-	15	-
0512Z	64	27	-	62	-

MILLER-MOORE 24 HOUR FORECAST ERROR

JUNE (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0600Z	160	7	-	159	-
0612Z	84	56	-	61	-
0700Z	77	76	-	11	-
0712Z	104	72	-	75	-
0800Z	172	38	-	166	-
0812Z	167	77	-	153	-
AVERAGE	119				

KATHY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1612Z	155	-	115	102	-
1700Z	97	56	-	83	-
1712Z	183	163	-	68	-
1800Z	202	192	-	62	-
AVERAGE	159				

LORNA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2200Z	155	148	-	44	-
2212Z	141	135	-	39	-
2300Z	56	-	53	23	-
2312Z	61	-	21	54	-
2400Z	145	-	35	140	-
2412Z	149	-	19	148	-
2500Z	115	-	15	115	-
2512Z	66	56	-	34	-
2600Z	59	54	-	24	-
2612Z	90	48	-	63	-
AVERAGE	104				

MILLER-MOORE 24 HOUR FORECAST ERRORS

NANCY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0900Z	103	40	-	97	-
0912Z	270	23	-	265	-
1000Z	37	-	7	34	-
1012Z	17	-	17	-	3
1100Z	120	7	-	119	-
1112Z	35	10	-	-	35
1200Z	45	45	-	5	-
1212Z	107	65	-	84	-
1300Z	158	55	-	145	-
1312Z	100	-	2	100	-
1400Z	133	-	68	-	122
1412Z	88	-	73	35	-
1500Z	98	70	-	-	70
1512Z	142	73	-	-	103
1600Z	75	-	27	-	69
1612Z	382	-	315	-	202
1700Z	469	-	469	-	-
AVERAGE	140				

OLGA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0912Z	71	-	59	-	38
1000Z	57	15	-	50	-
AVERAGE	64				

PAMELA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1000Z	72	3	-	70	-
1012Z	224	-	8	220	-
1100Z	300	87	-	287	-
1112Z	202	150	-	134	-

MILLER-MOORE 24 HOUR FORECAST ERRORS

PAMELA (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1200Z	135	54	-	120	-
1212Z	34	-	17	17	-
AVERAGE	161				

SALLY

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2700Z	63	61	-	21	-
2712Z	113	71	-	77	-
2800Z	166	73	-	150	-
2812Z	153	71	-	128	-
2900Z	141	63	-	123	-
2912Z	123	105	-	69	-
AVERAGE	127				

TILDA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2812Z	114	95	-	66	-
2900Z	110	108	-	-	5
2912Z	72	50	-	-	52
3000Z	70	-	62	-	32
3012Z	132	-	78	102	-
0100Z	193	50	-	182	-
0112Z	202	120	-	159	-
0200Z	172	95	-	123	-
0212Z	165	73	-	142	-
0300Z	100	43	-	-	93
0312Z	72	-	26	67	-
0400Z	77	-	32	-	66
0412Z	68	52	-	-	47
0500Z	197	153	-	-	133
AVERAGE	125				

MILLER-MOORE 24 HOUR FORECAST ERRORS

VIOLET

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0512Z	97	78	-	69	-
0600Z	15	-	12	12	-
0612Z	99	-	97	-	13
0700Z	102	-	92	38	-
0712Z	87	-	28	84	-
0800Z	118	23	-	115	-
0812Z	77	-	14	75	-
0900Z	67	-	53	-	38
0912Z	172	-	107	-	127
1000Z	327	-	245	-	210
1012Z	319	123	-	283	-
AVERAGE	135				

BILLIE

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2412Z	75	-	43	-	62
2500Z	56	-	13	-	52
2512Z	98	22	-	-	95
2600Z	55	-	-	-	55
2612Z	55	-	-	55	-
2700Z	58	-	50	22	-
2712Z	97	-	58	77	-
2800Z	97	-	88	43	-
AVERAGE	74				

CLARA

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
2800Z	257	162	-	162	-
2812Z	350	40	-	330	-
2900Z	278	-	35	273	-
2912Z	207	-	34	203	-

MILLER-MOORE 24 HOUR FORECAST ERRORS

CLARA (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
3000Z	182	45	-	172	-
3012Z	77	26	-	70	-
3100Z	107	-	25	102	-
3112Z	195	190	-	32	-
0100Z	80	-	30	70	-
AVERAGE	193				

DOT

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1012Z	178	114	-	142	-
1100Z	97	63	-	76	-
1112Z	45	44	-	-	11
1200Z	43	12	-	-	42
1212Z	69	-	8	-	67
1300Z	186	32	-	-	182
1312Z	152	-	29	-	148
1400Z	164	-	42	-	158
1412Z	82	-	28	-	75
1500Z	241	-	54	-	236
1512Z	183	-	68	-	168
AVERAGE	131				

ELLEN

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
0812Z	116	67	-	90	-
0900Z	52	47	-	22	-
0912Z	55	54	-	-	11
1000Z	42	40	-	-	13
1012Z	92	32	-	-	88
1100Z	37	35	-	12	-
1112Z	102	-	13	-	97

MILLER-MOORE 24 HOUR FORECAST ERRORS

ELLEN (CONT'D)

VERIFYING TIME	DISTANCE ERROR	MERIDIONAL ERROR N	MERIDIONAL ERROR S	ZONAL ERROR E	ZONAL ERROR W
1200Z	83	72	-	40	-
1212Z	83	63	-	44	-
1300Z	92	60	-	60	-
1312Z	76	65	-	28	-
AVERAGE	75				

AVERAGE DISTANCE ERROR-24 HR FORECASTS (175 CASES) . . . . . 119 MI

WACHHOLZ COORDINATION CHART

THIS CHART, WHICH IS INCLUDED AND DISCUSSED IN THIS BOOK, WAS USED IN THE 1960 AND 1961 SEASONS AS A TOOL TO EVALUATE THE EYE DATA REPORTS MADE BY THE AIRBORNE OBSERVER. IT IS AN AID TO DETERMINE THE RELIABILITY OF THE REPORT AND TO PROVIDE A CHECK ON THE OBSERVED SURFACE WIND OR PROVIDE A SURFACE WIND VALUE WHEN NONE WAS OBSERVED. THIS CHART, ALONG WITH THREE SEASONAL CLIMATOLOGY CHARTS, WAS COMPILED BY CAPTAIN EDWARD R. WACHHOLZ, USAF, IN APRIL AND MAY OF 1960 AFTER A SEASON OF FORECASTING TYPHOONS IN 1959 AT FWC/JTWC. THE GRAPHS WERE COMPILED FROM RECONNAISSANCE DATA FOR 1957, 1958 AND 1959 AND WERE INITIALLY TESTED ON 1956 DATA. THESE THREE YEARS PROVIDED THE MOST ACCURATE FLIGHT LEVEL WINDS AS DETERMINED BY THE APN-82 DOPPLER WIND MEASURING EQUIPMENT.

THE WACHHOLZ CHART IS BASED ON THE THEORY THAT ALL TYPHOONS DEVELOP IN HOMOGENEOUS AIR OVER AREAS OF SIMILAR CHARACTERISTICS AND THAT TYPHOONS ARE SIMILAR THERMODYNAMICALLY EXCEPT FOR DIFFERENCES IN INTENSITY. THESE VARIATIONS OF INTENSITY ARE DUE TO THERMAL, LATITUDINAL AND LONGITUDINAL CONSIDERATIONS.

THE CHART (FIG. 1) RELATES MINIMUM 700 MB HEIGHT (FT), MAXIMUM 700 MB TEMPERATURE (^{o}C), AND MINIMUM SURFACE PRESSURE (MB), AS MODIFIED BY LATITUDE, TO MAXIMUM 700 MB WIND SPEED (KTS) AND MAXIMUM SURFACE WIND (KTS). IT IS BASED ON THE FOLLOWING FORMULAE:

$$\text{SFC WIND MAX} = \left[17 - \left(\frac{\theta - 15}{5}\right)\right]\sqrt{372 - \frac{7HM}{28}} \qquad (1)$$

$$\text{700 MB WIND MAX} = 50 + (.5 + \frac{SFCM}{500})\ (SFCM \quad 50) \qquad (2)$$

θ REPRESENTS THE LATITUDE OF THE TYPHOON EYE
7HM IS THE 700 MB MINIMUM HEIGHT OF THE EYE IN FT
SFCM IS THE SURFACE WIND MAX AROUND THE EYE IN KTS

THE BASIS OF THESE FORMULAE IS THE ORIGINAL FORMULA BY DR. ROBERT FLETCHER WHO IS PRESENTLY DIRECTOR OF SCIENTIFIC SERVICES, AIR WEATHER SERVICE. THIS FORMULA IS SHOWN BELOW:

$$\text{SFC WIND MAX} = 16\sqrt{1010 - P_c} \qquad (3)$$

1010 REPRESENTS THE PRESSURE IN MB AT THE "BAR" OF THE TYPHOON AND MAY BE ADJUSTED IF THE "BAR" PRESSURE DIFFERS.
P_c IS THE CENTER PRESSURE OF THE TYPHOON OR HURRICANE IN MB.

NOTE ON THE COORDINATION CHART THAT THE 700 MB-SURFACE WIND RELATIONSHIP IS DIRECT (THEY ARE THE SAME AT 50 AND 250 KTS ONLY) AND THAT THE SURFACE PRESSURE-700 MB HEIGHT IS ALSO DIRECTLY RELATED. WHEN THE SURFACE PRESSURE OR 700 MB HEIGHT IS KNOWN, FIND IT ON THE GRAPH THEN FOLLOW HORIZONTALLY TO THE CORRECT LATITUDE; FROM THERE, EXTEND VERTICALLY TO THE SURFACE WIND OR TO THE 700 MB WIND.

INFORMATION MOST FREQUENTLY USED TO DETERMINE THE SURFACE WIND IS THE 700 MB HEIGHT AND THE 700 MB WIND WHICH ARE ACCURATELY MEASURED BY THE AIRCRAFT. THE SURFACE PRESSURE IS MOST FREQUENTLY OBTAINED FROM DROPSONDE EQUIPMENT AND AVAILABLE AS RAW UNCORRECTED DATA AT TIME OF CHART USE. ITS VALUE VARIED AT TIMES FROM THE CORRECTED PRESSURE AVAILABLE LATER. THE 700 MB TEMPERATURE PARAMETER HAS BEEN FOUND TO BE LEAST USEFUL DUE TO THE FACT THAT IT IS REPORTED IN WHOLE DEGREES, AND A SMALL VARIATION IN TEMPERATURE REPRESENTS A LARGE VARIATION OF OTHER FEATURES IN THE GRAPH. THIS GRAPH WORKS ONLY FOR CIRCULATIONS THERMODYNAMICALLY CLASSIFIED AS TYPHOONS FROM DATA DERIVED FROM WITHIN THE EYE OF THE TYPHOON.

AT THE REQUEST OF HEADQUARTERS AIR WEATHER SERVICE, USAF, AN EVALUATION OF THE GRAPH HAS BEEN MADE, BASED ON INFORMATION AVAILABLE TO JTWC DURING THE 1961 SEASON. THE EVALUATIONS HAVE BEEN DIVIDED INTO TWO SECTIONS. FIRST, RELATING OBSERVED INFORMATION AT A NEARBY LAND OR SHIP STATION TO AN EYE DATA REPORT AND THE SURFACE WIND THAT THE VARIOUS PARAMETERS OF THE EYE DATA REPORT WILL PRODUCE ON THE WACHHOLZ CHART. THE COMPARISONS ARE NOT SIGNIFICANT BECAUSE OF DISTANCE OR TIME VARIATIONS AND LIMITED DATA. THE SECOND EVALUATION CONCERNS THE COMPARISON OF THE OBSERVED PARAMETERS TRANSLATED INTO SURFACE WIND SPEED VALUES WITHIN THE WACHHOLZ CHART ITSELF. IN ADDITION, THE CHART IS EVALUATED AGAINST OBSERVED WINDS OF EACH EYE DATA REPORT.

THE SECOND EVALUATION WAS ACCOMPLISHED IN THE FOLLOWING MANNER:

A. THE REPORTED SEA LEVEL PRESSURE, 700 MB HEIGHT, 700 MB TEMPERATURE AND 700 MB WIND WERE CONVERTED INTO A SURFACE WIND VALUE FOR ALL TYPHOON EYE DATA.

B. EACH CONVERTED PARAMETER AND THE OBSERVED SURFACE WIND WAS COMPARED WITH THE 700 MB WIND CONVERTED TO A SURFACE WIND VALUE ON SCATTER DIAGRAMS.

C. THE DATA WAS SCREENED TO REMOVE EYE DATA REPORTS THAT WERE IN ERROR WHEN COMPARED CHRONOLOGICALLY. FOR EXAMPLE, ASSUME THAT IN ONE REPORT ALL PARAMETERS APPEARED REASONABLE AND IN THE FOLLOWING REPORT THE 700 MB HEIGHT INCREASED IN VALUE, THE SURFACE PRESSURE DECREASED, AND THE REMAINDER OF THE INFORMATION WAS UNCHANGED. THE LATTER REPORT WOULD BE REMOVED FROM THE SAMPLE TO BE EXAMINED. IN THIS MANNER DATA THAT APPEARED TO CONFORM TO THE WACHHOLZ CHART AS WELL AS SOME DATA THAT DID NOT CONFORM WERE REMOVED.

LAND/SHIP OBSERVATIONS COMPARED WITH WACHHOLZ CHART

STATION/WIND KTS	DATE/TIME	WACHHOLZ CHART	ACFT SFC WND	FIX FROM STATION/REMARKS
ULITHI/29	252355Z	T83,H82,W68,P68	80 KTS	TESS, 252145Z MAR, 180 MI W
IWO JIMA/G 57	291112Z	T100,H78,W80,P60	70 KTS	IDA, 290800Z JULY, 48 MI SE
BATANNES/12	060000Z	T58,H94,W80	100 KTS	JUNE, 060150Z AUG, 30 MI NNE
BATANNES/40,G 65	241100Z	T154,H108,W105,P110	150 KTS	LORNA, 240900Z AUG, 54 MI E
NPRE (SHIP)/70	110900Z	T90,H144,W160,P138		PAMELA, 110808Z SEPT, 206 MI ENE, 22.4N 124.3E
TACHIKAWA/25,G 41	092330Z	T104,H70,W95,P70	80 KTS	VIOLET, 092130Z OCT, 100 MI S
YOKOSUKA/48,G 74	092230Z	T104,H70,W95,P70		VIOLET, 092130Z OCT, 62 MI S
YAP ATOLL/G 35	240130Z	T62,H62,P68	50 KTS	BILLIE, 232240Z OCT, 295 MI NE
IWO JIMA/30,G 51	270052Z	T87,H85,W20	35 KTS	BILLIE, 262250Z OCT, 77 MI E
IWO JIMA/29,G 37	132138Z	T88,H87,W120,P87	140 KTS	DOT, 132200Z NOV, 320 MI ESE

NOTE:

G - GUSTS
T - TEMPERATURE, 700 MB CONVERTED TO A SURFACE WIND VALUE, KTS
H - HEIGHT, 700 MB CONVERTED TO A SURFACE WIND VALUE, KTS
W - WIND, 700 MB CONVERTED TO A SURFACE WIND VALUE, KTS
P - REPORTED SEA LEVEL PRESSURE CONVERTED TO A SURFACE WIND VALUE, KTS

D. THE CONVERTED 700 MB OBSERVED WIND WAS SUBTRACTED FROM THE CONVERTED VALUES OF THE 700 MB HEIGHT, SEA LEVEL PRESSURE, 700 MB TEMPERATURE, AND FROM THE REPORTED SURFACE WIND. THIS DIFFERENCE WAS PLOTTED AGAINST NUMBER OF CASES TO PRODUCE A GRAPH OF EACH PARAMETER AS INDICATED. FIGURE 2 REPRESENTS 97 CASES; FIGURE 3, 103 CASES; FIGURE 4, 90 CASES AND FIGURE 5 REPRESENTS 99 CASES. THE VARIATION IN CASES REPRESENTS FAILURE TO REPORT A PARTICULAR PARAMETER BY THE AIRBORNE OBSERVER. FROM THE ORIGINAL UNCORRECTED SAMPLE OF 119 CASES, THE MAXIMUM POSSIBLE NUMBER OF CASES WOULD BE 103.

THE 700 MB WIND, DERIVED FROM THE DOPPLER WIND REPORTING SYSTEM IS THE MOST ACCURATE INFORMATION PROVIDED BY THE OBSERVER AND WAS USED AS THE CONTROL FROM WHICH OTHER REPORTED DATA WOULD VARY. THERE IS A HUMAN ELEMENT INVOLVED IN COLLECTING THE OPTIMUM 700 MB WIND SINCE EYE PENETRATIONS BY SKILLED CREWS ARE USUALLY SAFE ONES, FOR THE AIRCRAFT COMMANDER IN COORDINATION WITH OTHER CREW MEMBERS WILL SELECT THE WEAKEST ZONE OF THE WALL CLOUD TO PENETRATE. THIS IS LIKELY TO BE THE AREA OF LEAST VERTICAL MOTION AS WELL AS LEAST HORIZONTAL MOTION WITHIN THE WALL CLOUD; THUS, THE MAXIMUM OBSERVED 700 MB WIND IS NOT TRULY REPRESENTATIVE OF THE OVERALL CONDITION OF THE WIND AT THAT LEVEL. BECAUSE OF THIS, THE 700 MB HEIGHT IS CONSIDERED TO BE MORE REPRESENTATIVE. IT IS MEASURED WITHIN THE TYPHOON EYE AND THERE ARE FEW PROBLEMS TO SECURING A REASONABLY ACCURATE VALUE THAT REPRESENTS THE OVERALL CONDITION OF THE TYPHOON. A COMPARISON BETWEEN THE 700 MB HEIGHT AND THE 700 MB WIND, BOTH REDUCED TO A SURFACE WIND VALUE, REVEALS 23 CASES BETWEEN PLUS 5 KTS AND MINUS 5 KTS, 25 CASES BETWEEN PLUS 6 AND PLUS 15 KTS INCLUSIVE. THIS DATA PRODUCES A CURVE THAT INCLUDES 65 PERCENT OF CASES BETWEEN MINUS 15 AND PLUS 15 KTS. THE SCATTER DIAGRAM INDICATES THAT 60 PERCENT OF THE DATA WAS WITHIN 10 PERCENT OF THE SPEED VALUE AXIS FOR ALL SPEEDS. THIS IS PROBABLY WITHIN THE LIMITS OF CONSISTENT OBSERVING AND FORECASTING OF TYPHOON INTENSITIES.

A COMPARISON BETWEEN THE REPORTED SURFACE WIND AND THE 700 MB WIND REDUCED TO A SURFACE WIND VALUE INDICATES THAT THE REPORTED WIND WAS FASTER THAN THE COMPUTED WIND, AND THE CURVE IS SKEWED SIMILARLY TO THAT OF THE 700 MB HEIGHT CURVE. THE BOUNDARY OF MINUS 15 TO PLUS 15 KTS INCLUDES 40 PERCENT OF THE DATA, AND 31 PERCENT OF THE DATA WAS WITHIN 10 PERCENT OF THE SPEED VALUE AXIS FOR ALL SPEEDS ON THE SCATTER DIAGRAM.

THE MINIMUM SEA LEVEL PRESSURE CURVE INDICATES THAT THIS PRESSURE PROVIDES A SURFACE WIND SPEED VALUE HIGHER THAN THE 700 MB WIND, 58 PERCENT OF THE DATA BETWEEN MINUS 15 AND PLUS 15 KTS, AND THAT 49 PERCENT OF THE DATA WAS WITHIN 10 PERCENT OF THE SPEED VALUE AXIS FOR ALL SPEEDS ON THE SCATTER DIAGRAM.

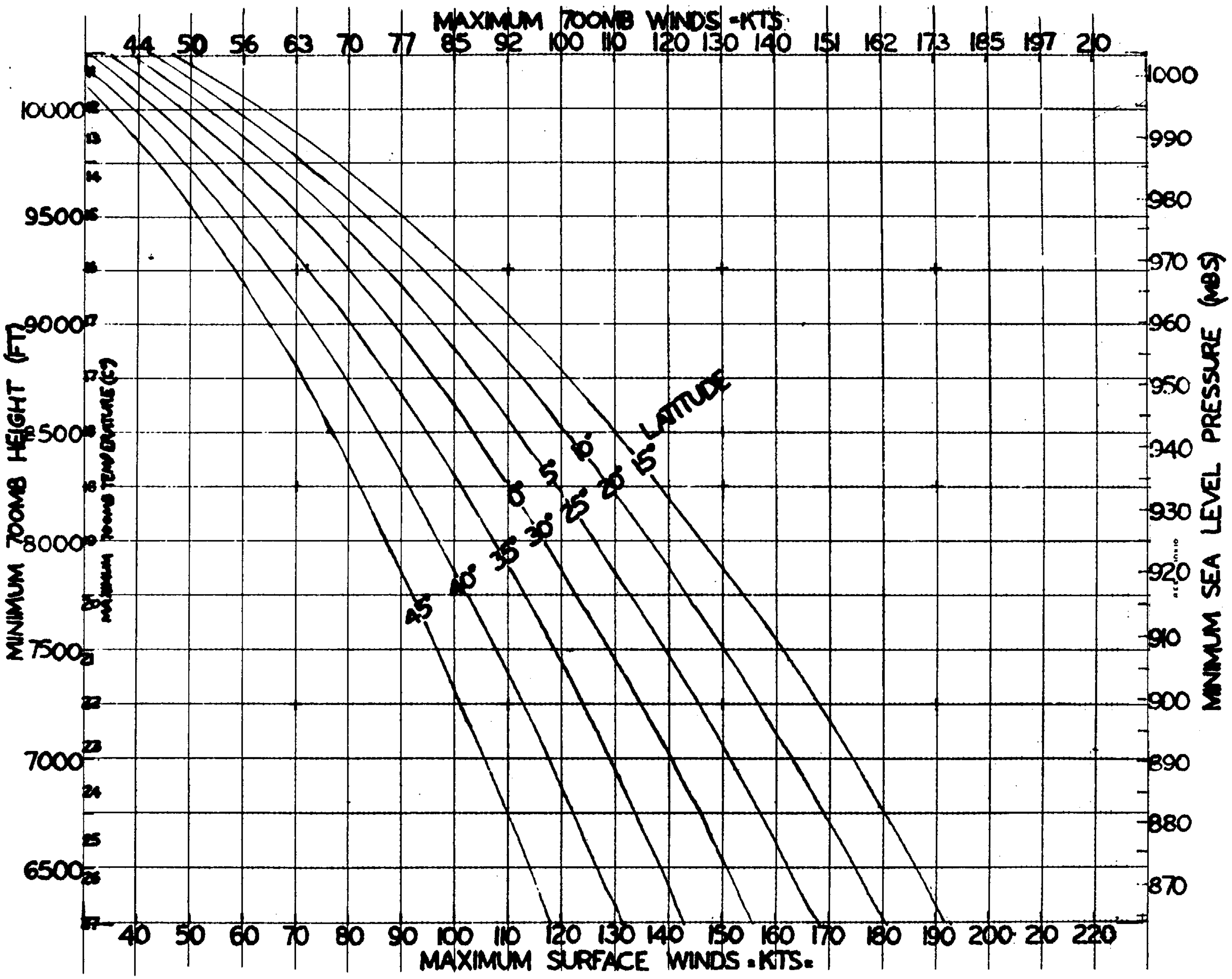
THE 700 MB TEMPERATURE CURVE PROVIDES AN INTERESTING VARIATION FROM THE OTHER CURVES. ONLY 37 PERCENT OF THE DATA RANGES BETWEEN PLUS AND MINUS 15 KTS, 40 PERCENT OF THE DATA IS WITHIN 10 PERCENT

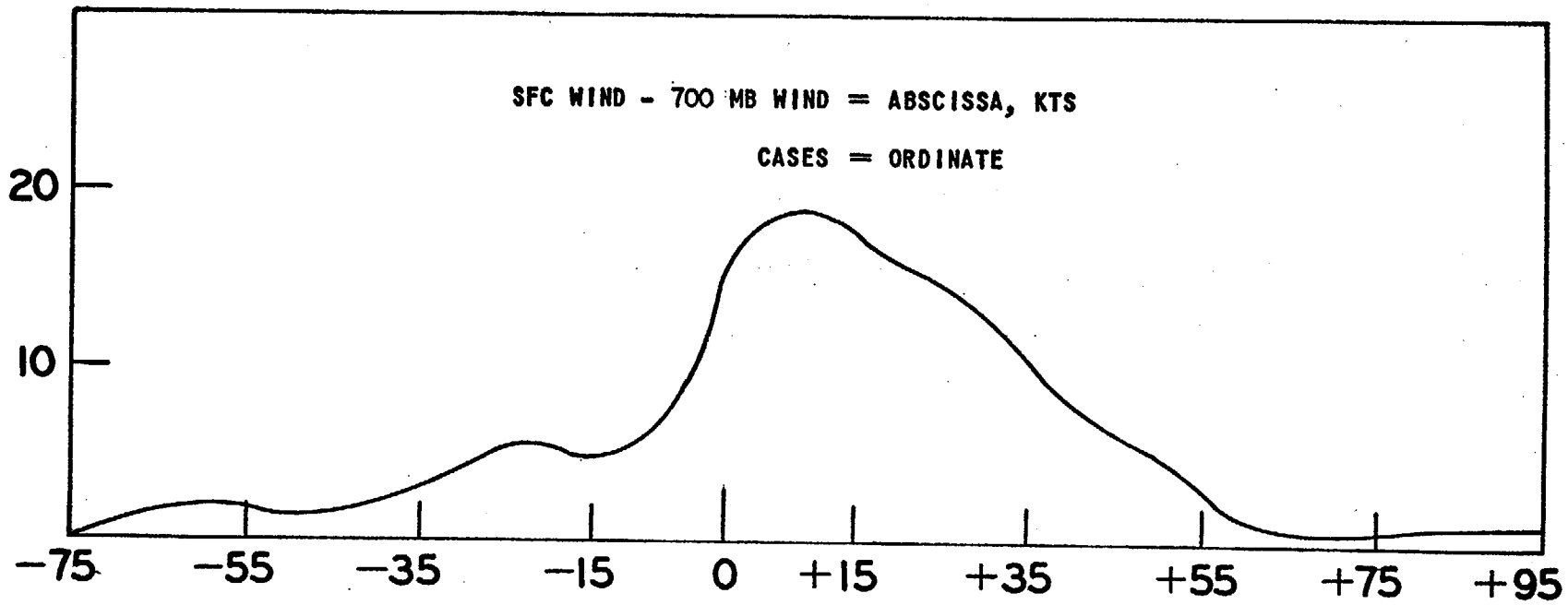
OF THE SPEED AXIS, AND EXPERIENCE INDICATES THE TEMPERATURE TO BE LEAST RELIABLE OF ALL DATA TO PROVIDE A SURFACE WIND VALUE. EXAMINATION OF THE DATA REVEALS THAT WHEN THE TEMPERATURE IS WARMER THAN NORMAL ACCORDING TO THE WACHHOLZ CHART, THE SURFACE WINDS FREQUENTLY INCREASE IN SPEED; THAT IS, THE TYPHOON INTENSIFIES. WHEN THE TEMPERATURE IS COOLER THAN WOULD NORMALLY BE EXPECTED, THE WIND SPEED DECREASES. THIS RELATIONSHIP WILL BECOME A RESEARCH PROJECT OF THE COMING YEAR TO DETERMINE THE SIGNIFICANCE OF THIS INDICATION.

THE QUESTION OF BIAS OF REPORTED DATA HAS ARISEN SEVERAL TIMES CONCERNING THE USE OF THE WACHHOLZ CHART BY JTWC. THIS POSSIBILITY CERTAINLY EXISTS AND CANNOT BE DISCOUNTED. THERE IS SOME SIMILARITY TO THE VARIATION CURVES PRESENTED. THE SCATTER DIAGRAMS AND THE DISTRIBUTION OF THE DATA ON THE VARIATION CURVES DO NOT SUPPORT THE USE BY THE AIRBORNE OBSERVER OF THE WACHHOLZ CHART ITSELF OR ANY OTHER TOOL THAT CONSISTENTLY RELATES SOME OBSERVED PARAMETER TO THE REPORTED SURFACE WIND ON A DAY TO DAY BASIS THROUGHOUT THE YEAR.

EXAMINATION OF AVAILABLE DATA PRODUCES TWO CONCLUSIONS. FIRST, AN AVERAGE OF THE 700 MB WIND, MINIMUM SEA LEVEL PRESSURE AND 700 MB HEIGHT WILL PRODUCE A SURFACE WIND VALUE SLIGHTLY LESS THAN THAT REPORTED BY THE AIRBORNE OBSERVER ON A SEASONAL BASIS. SECOND, THE WACHHOLZ CHART, THE FIRST TO CORRELATE ALL SIGNIFICANT MEASURED PARAMETERS WITHIN THE TYPHOON EYE, IS AN EXCELLENT TOOL FOR USE BY THE TYPHOON DUTY OFFICER AS INDICATED IN THE FIRST PARAGRAPH.

SUFFICIENT DATA IS NOW AVAILABLE FROM THE 1960 AND 1961 SEASONS TO EFFECT SEVERAL MINOR CHANGES TO THE CHART, A PROJECT WHICH CAPTAIN WACHHOLZ INDICATED TO BE DESIRABLE WHEN THIS SUPPORTING DATA BECAME AVAILABLE.

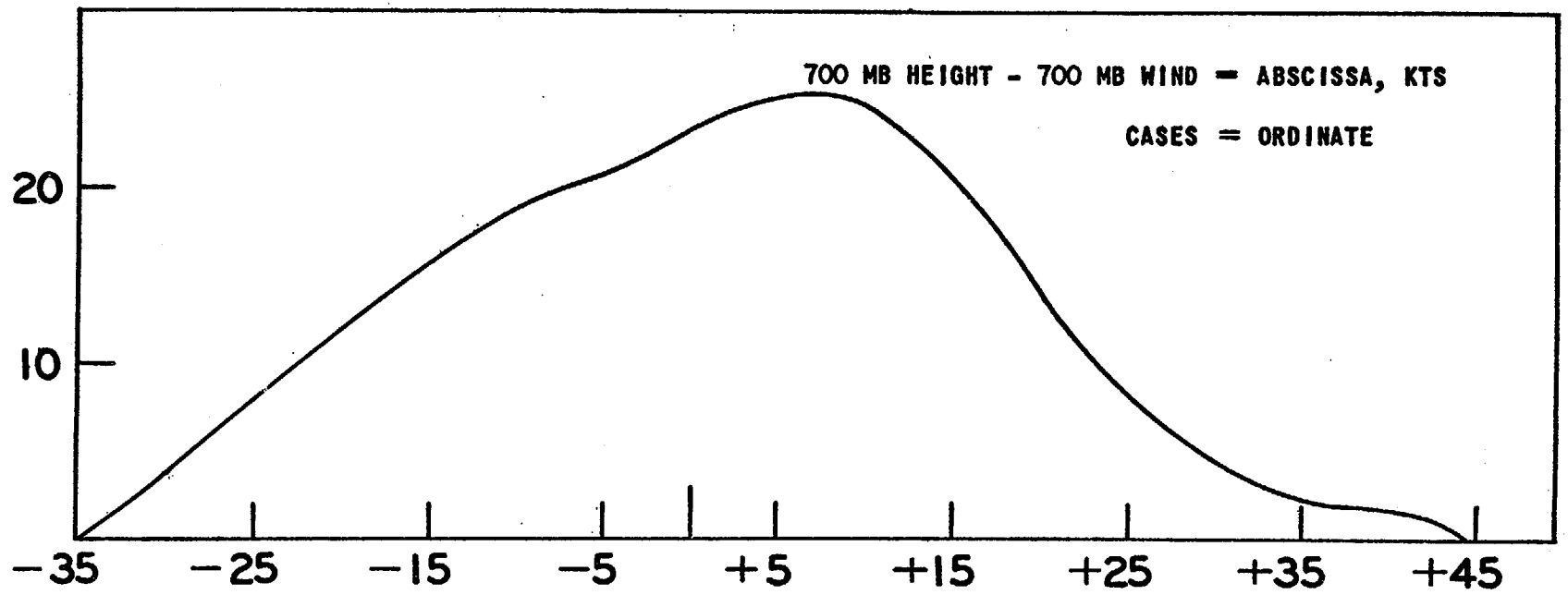

MAXIMUM 700MB WINDS - KTS
44 50 56 63 70 77 85 92 100 110 120 130 140 151 162 173 185 197 210
MINIMUM 700MB HEIGHT (FT)
10000 9500 9000 8500 8000 7500 7000 6500
MINIMUM SEA LEVEL PRESSURE (MBS)
1000 990 980 970 960 950 940 930 920 910 900 890 880 870
LATITUDE
0° 5° 10° 15° 20° 25° 30° 35° 40° 45°
MAXIMUM SURFACE WINDS - KTS
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220



SFC WIND - AS REPORTED BY AIRBORNE OBSERVER

700 MB WIND - CONVERTED TO SURFACE WIND VALUE

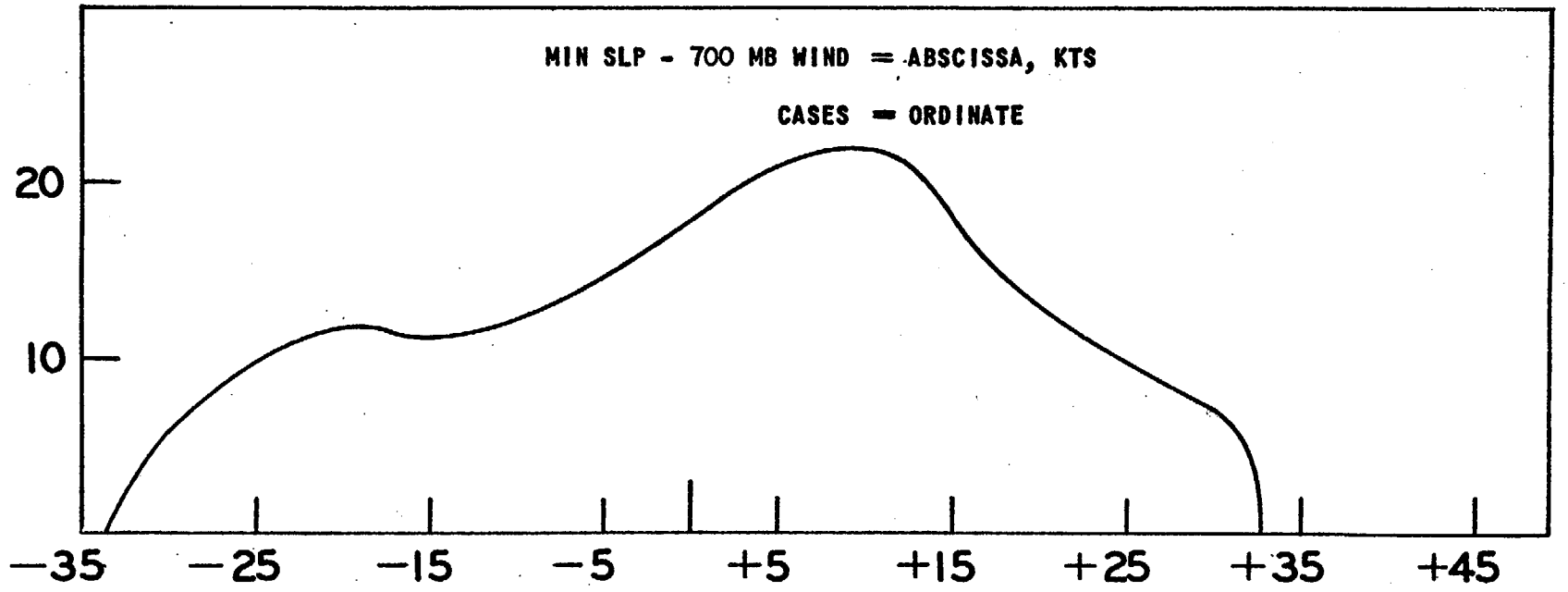
FIG. 2



700 MB HEIGHT - CONVERTED TO SURFACE WIND VALUE

700 MB WIND - CONVERTED TO SURFACE WIND VALUE

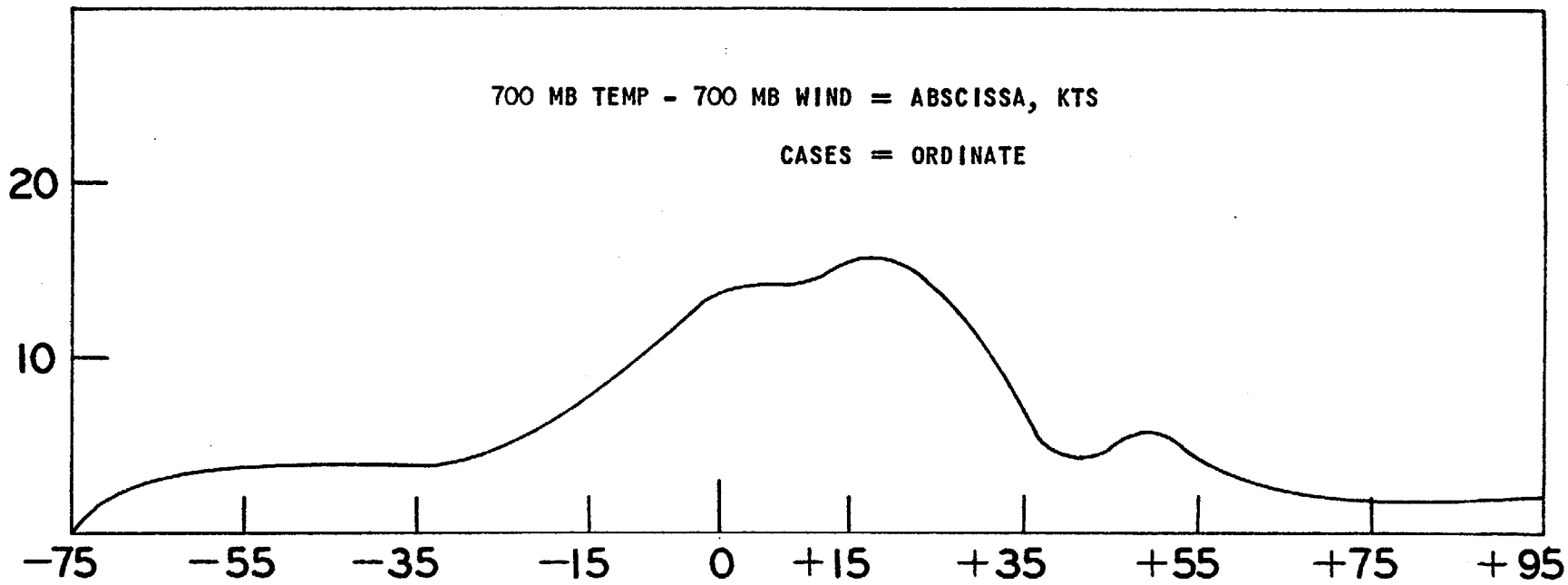
FIG. 3



MIN SLP - CONVERTED TO SURFACE WIND VALUE

700 MB WIND - CONVERTED TO SURFACE WIND VALUE

FIG. 4



700 MB TEMP - CONVERTED TO SURFACE WIND VALUE

700 MB WIND - CONVERTED TO SURFACE WIND VALUE

FIG. 5